Appendix A: Topographic Data of Upper Quinault River

This appendix describes new LiDAR and channel survey topographic data collected in 2002 for this study. Also discussed are a topographic survey from 1929 and the comparison of this data to 2002 river elevations.

2002 LiDAR and Channel Survey Data

Data Collection Reach

The longitudinal extent of data collected was between the upper end of Lake Quinault to the confluence of the North and East Forks of the Quinault River, about 12 km upstream from the lake (see Figure 1 in main report). The lateral extent of topographic data collected was across the valley floor from valley wall to valley wall, on average about 2 miles.

Establishment of Permanent Survey Control Network and Project Datum

During the week of September 23, 2002, a permanent survey control network was established along the study reach from the Forks Bridge to Lake Quinault by Reclamation surveyors using global positioning system (GPS) equipment (see attachment 1 for more documentation). The network was tied to a National Geodetic Monument and referenced to *UTM 1983, National Geodetic Vertical Datum 1988, Zone 10, meters*. Both the river survey data and LiDAR data collected utilized this network so the data could be properly integrated. This network can also be used in any future data collection along the Quinault River to allow direct comparison of data in the same projection and datum. All GIS data mapped for our study was accomplished in this datum.

Acquisition of Aerial Photography and LiDAR Data

Aerial photographs were acquired on October 23, 2002 by Walker Associates and LiDAR data was acquired on October 30, 2002 by Horizon, Inc. It was desired to have the LiDAR and aerial photography overlap the low flow channel bottom survey data collected boat in early October 2002 so a continuous digital terrain surface of the valley bottom could be generated. Because winter flooding can often result in changes of the channel geometry, the data can be better integrated if collected all at the same time. The aerial photography and LiDAR acquisition date was chosen based on when the leaves were beginning to fall off the trees allowing for more penetration to the ground, photo panels were in place, river flows were low, and weather was favorable. Photo panels were placed within the study reach for the photogrammetric process of rectifying the aerial photography during the week of September 23, 2002. Due to the dense vegetation and narrow valley along the study reach, there were limited locations where photo panels could be easily visible in the aerial photography. As a result, some photo panels were located in areas along the active river channel bars that were vulnerable to winter flooding.

Processing of LiDAR data and new aerial photography

Processing of the new 2002 LiDAR data and aerial photography was completed by Horizon and delivered to Reclamation in the following formats:

1. Multiple return ascii data
2. First return ascii data
3. Bare earth ascii data (final processed ground elevation data)
4. Bare earth 2m grid data
5. Breakline work for LiDAR processing
6. Metadata for data

River Channel & Delta Survey

A river channel survey was accomplished by Bureau of Reclamation with a boat equipped with a depth sounder, GPS equipment and total station tracking equipment from September 28, 2002 to October 2, 2002 (Figure 1). In some sections of shallow flow where the boat could not be floated, channel bottom was measured by walking rather than using depth sounding equipment on the boat. The goal of the survey was to map the topography of the low flow wetted channel which can not be acquired by commercially available LiDAR techniques. By combining the underwater data with the LiDAR data, a continuous topographic map of the river and floodplain can be generated. A survey of the upstream portion of Lake Quinault delta was also accomplished on October 3, 2002. The data from the river channel and upstream portion of the reservoir survey is available in ASCII format geo-referenced to the same datum as the LiDAR data. The average discharge at the outlet of Lake Quinault during the survey was 407 ft^3/s (Table 1).

Figure 1. Bill Armstrong and Tim Randle on survey raft equipped with depth sounder and GPS survey equipment. Photograph taken September 30, 2002.

Table 1. Discharge estimates for channel and reservoir survey period from USGS gage "12039500 QUINAULT RIVER AT QUINAULT LAKE, WASHINGTON".

Survey Date	Estimated Start Collection	Estimated End Collection	Daily Average Gage Q (ft3/s)
9/28/2002	10:00 AM	6:00 PM	423
9/29/2002	10:00 AM	6:00 PM	411
9/30/2002	10:00 AM	6:00 PM	403
10/1/2002	10:00 AM	6:00 PM	393
		Total Average Q	407

A longitudinal profile of the thalweg and water surface elevation measured was produced (see Attachment 3). This profile was used to compute the average hydraulic slopes of the river (Table 2), and characterize the presence of pools and hydraulic controls. The average hydraulic slopes were computed by connecting a straight line between the top of hydraulic controls (riffles and rapids). Where the line exhibited a significant shift in alignment over several hydraulic controls, a new slope was computed. Two small sections of 0.2 kilometers in length appeared to be transition sections between steeper to flatter slopes, and slope values were not computed.

Table 2. Average hydraulic slopes of river channel based on water surface elevation data from October 2002 channel survey (see Attachment 3 for profile plots).

KM	Elevation (m)	Slope (m/m)	Slope (%)	Distance (km)
0.109	56.014			
0.1 to 2.7	61.668	0.0022	0.22	2.57
2.7 to 2.9	62.852	0.0058	0.58	0.21
2.9 to 4.6	66.356	0.0021	0.21	1.68
4.6 to 6.3	71.460	0.0029	0.29	1.76
6.3 to 6.6	71.536	0.0002	0.02	0.31
6.6 to 12.6	90.900	0.0032	0.32	6.00
12.6 to 14.0	95.665	0.0034	0.34	1.39
14.0 to 15.4	102.255	0.0047	0.47	1.41
15.4 to 17.3	107.924	0.0031	0.31	1.83

The largest rapid (or drop) in water surface elevation measured in October 2002 was 2.8 meters in height between river kilometer 15.1 to 15.4. The deepest pool measured was 5 meters in depth at river kilometer 17.1. From river kilometer 0 to 7.5, the profile shows a combination of shallow riffle sections with water depths less than 1 meter interspaced with rapid and pool complexes. The rapids measured 0.3 to 0.8 meters of drop and pools at the downstream end of the rapids had 1 to 2.3 meters in depth. From river kilometer 7.5 to 8.3, there is a steeper rapid and pool complex (relative to the downstream reach) with a 0.0068 slope. Between river kilometers 8.3 to 9.0, the river in 2002 had one deep pool and flatter slope of 0.0014 (relative to rest of study reach). The deep pool existed where the river ran east across the valley into a riprapped section of road. This section of river shifted to the south side of the floodplain in a flood following the survey. Between river kilometer 9 to 14.4, a rapid and pool complex is again interspaced with shallow riffles, but the pools are only 1 to 1.5 meters in depth. Between river kilometer 14.4 to 18, a rapid and pool complex were measured with deepest pools existing where the river ran along bedrock outcrops on the south side of the river (along the South Shore Road) (see Figure 2). Additional scour pools existed in the study reach where log jams interacted with the low flow river channel. In some cases the maximum depth of these scour pools could not be measured because the boat had to be portaged around the log jams and the depth was too deep to wade by foot.

Figure 2. Example of deep pool near bedrock outcrop along South Shore Road. Note the riprap placed to protect South Shore Road on either side of the bedrock. Photograph taken September 28, 2002.

Digital Terrain Surface (DTM)

A digital terrain model (DTM) was generated by combining the LiDAR data with the river survey data. This was accomplished by blocking out areas of wetted channel in the LiDAR data set and, where available, replacing it with channel bottom data. This DTM (TIN surface) represents a continuous surface of the study reach from valley wall to valley wall, from Lake Quinault upstream to the Forks. Contour data (2m) was also generated from the DTM surface, along with a hillshade representation of the topography.

Quality Control Check on LiDAR Data

The vertical accuracy of the LiDAR data was of interest because elevation differences within the study reach were used to distinguish geologic surfaces, historic channels, and many other floodplain features. The LiDAR data contract was written to establish topographic data of the ground that could generate an accurate 2m-contour interval. This is a generally accepted standard for this geographic region in the Pacific Northwest based on the presence of dense vegetation where it is difficult for LiDAR data to penetrate to the valley floor. The 2002 rectified aerial photographs were used by the contractor to process the data and determine areas where LiDAR could not be generated due to wetted channel or heavy vegetation.

To provide a cursory test of the accuracy of the data, the bare earth LiDAR data elevations were compared to two other elevation data sets: 1) elevation data collected by GPS survey equipment at unique points throughout the study reach where photo panels were surveyed, and 2) at four cross-sections surveyed by total stations all roughly located in the middle of the study reach and linked to the same GPS network. The points at photo panel locations were collected using static GPS methods (high level of accuracy due to longer occupation time) and generally in open, unvegetated areas with a clear view of the sky where LiDAR data should do reasonably well. The four cross sections contained a mixture of open, unvegetated areas and areas both covered in vegetation and some areas of wetted channel within the floodplain forest.

A total of 374 GPS elevation data points were compared to LiDAR results (Figure 3). Using a standard testing procedure indicates that contours developed from this data should be accurate to .42 meters 95% of the time (Federal Geographic Data Committee, 1998). Although this is better than the estimated 2-m accuracy, because only a small number of points within the study area were compared, many of which were in open relatively unvegetated areas, it may have come out differently with more data. However, it does indicate the LiDAR data should provide a reasonable interpretation of the topography in the study area at an appropriate level of accuracy for this study.

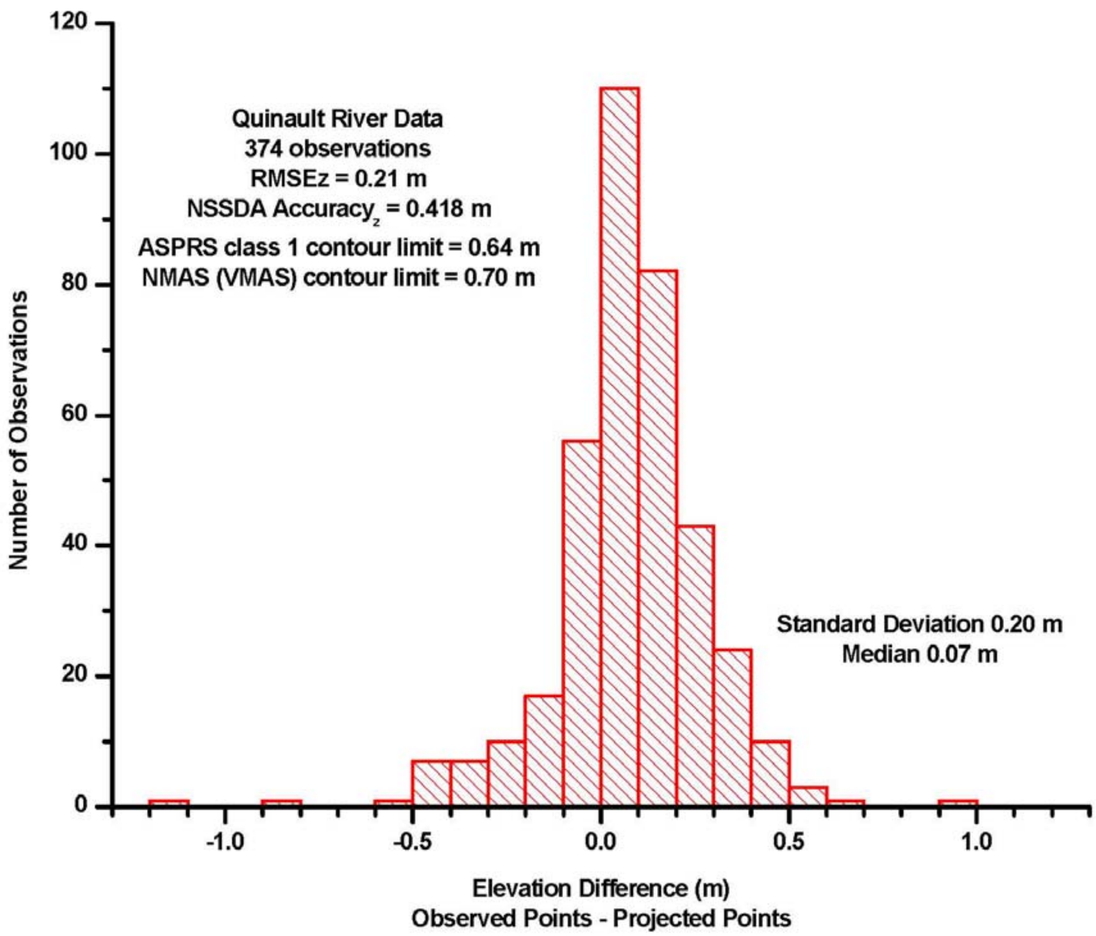


Figure 3. Results of point comparison between LiDAR data and GPS points.

As an additional check, the ground survey data from the four cross-sections were compared to LiDAR data processed into a 2m grid, and to a digital terrain surface (TIN surface) created from a combination of the river channel survey data and all LiDAR data points (see Attachment 2 for cross section plots). In general, the LiDAR data compared to ground survey data within 0.5 meter, which is reasonable given the natural variation in ground surface in this region that can be observed in the field.

The LiDAR did a good job of indicating breaks in terrace surfaces and historical channel paths. Where multiple survey data points were available of the channel bottom within a small area, the TIN correctly represents the thalweg better than the 2m grid LiDAR data alone. However, when there is only one thalweg data point the tin appeared to often average out the elevation with surrounding points which would create a higher elevation thalweg than exists in reality. A more robust tin generation method could help eliminate this problem. The typical error in thalweg measurements from the TIN was not much greater than the diameter of a typical cobble sized particle on the bed. Most larger ponded areas or inundated river sections were identified as "no data" areas by the contractor (Horizon) and no LiDAR data is available. In these areas the processed TIN and 2m LiDAR grid “connects the dots” between closest areas where data was available, and ground survey data is more representative of the actual topography. In some small ponded areas, LiDAR data is provided and most likely represents the water surface rather than actual ground elevation. In cross section 1 the LiDAR was lower in elevation than the ground survey data and when combined into a TIN created an uneven (unrealistic) surface that differed by about 1 meter.

It is concluded that using a combination of measured river channel and LiDAR data did a reasonable job of representing the topography and was appropriate for developing cross-sections over a large lateral area to represent average reach topography. However, cross sections or surfaces generated for modeling should be evaluated for possible modification in areas where the data looks non-typical of other similar topographic areas. Areas in dense vegetation or wetted channel showed the most differences. Subsequent design level analysis for restoration projects may require additional ground survey data in wetted or densely vegetated areas.

Historical River Channel Survey Data

A copy of a historical U.S. Geological Survey (USGS) map was acquired from the University of Washington library (call number G4282.Q52 1929.G4) that documents planview and a longitudinal profile survey of the river surface accomplished in 1929 (Jones, 1929). The contour interval shown on the map is 50 feet for land areas, and 5 feet on the river surface. The vertical datum of the map is mean sea level, shows township and section lines, and an approximate mean declination of 1929. The river surface appears to represent the low flow channel(s) as delineated within the active channel. Gravel bars are denoted on the map, along with prominent roads and infrastructure, but vegetation is not illustrated. The planview map appears to be tied to section lines, although the planview copy obtained does not show square quarter sections which may imply some error in the original map or the copying process. A longitudinal profile plot of the river surface in 10 foot intervals from the same 1929 survey (referred to as Sheet B by USGS) was also available that did not have any visible distortion on the photocopy.

Adjustment of 1929 horizontal datum

It was of interest to compare the 1929 channel position to positions generated from other historical aerial photographs and maps, and the 1929 water surface profile to survey data collected in October 2002. This meant the horizontal and vertical datum of the 1929 map had to be adjusted to match the present datum of survey data collected in October 2002 (Horizontal: UTM 1983, Zone 10, meters; Vertical: NGVD 1988, meters).   The 1929 planview image was georeferenced to electronic versions of 1:24,000-scale topographic maps of the U.S. Geological Survey (Lake Quinault East, Finley Creek, and Bunch Lake quadrangles) to allow mapping of channel position. The topographic maps had an original or native projection of UTM, Zone 10, NAD 27, meters, but had been reprojected into UTM, Zone 10, NAD 83, meters. The RMS errors for the projection were not documented and the map would need to be re-georeferenced to determine the accuracy. However, the plotted position after our georeferencing showed the channel passing through areas known to be bedrock, so there was a substantial error known to exist. The 1929 channel position was manually adjusted based on our best interpretation and judgment call as to where the channel would have flowed. Comparisons were made to previous maps from 1906 and 1897 and to 1939 aerial photographs the closest documentation of channel position prior to and after the 1929 map.

Adjustment of 1929 vertical datum

The 1929 vertical map datum was recorded as mean sea level, but not enough information was given to provide a known transformation to the present vertical datum and, therefore, had to be manually adjusted to match 2002 elevation data. As a first step the 1929 elevations were adjusted to the 1988 datum by adding 3.48 feet, the standard conversion from 1929 to 1988 vertical datum for this region as determined from Corpscon datum conversion program (compiled by Army Corps of Engineers, http://crunch.tec.army.mil/software/corpscon/corpscon.html). The elevations were then converted from feet to meters.   This resulted in a lake elevation of 58.4 m, significantly higher than the lake elevation of 55.9 m measured in 2002 (river discharge of 400 ft^3/s in 2002). As an alternative approach, it was determined the elevations could be adjusted using landmarks that would have the least likelihood to have not drastically changed within the study reach between 1929 and 2002, mainly the Quinault lake elevation.

The lake elevation is controlled by a naturally formed moraine at the outlet of Lake Quinault. If the channel bed near the moraine has not vertically changed significantly since 1929, it can be assumed the influence on the lake surface elevation for a given discharge should be similar between 1929 and 2002. By comparing the stage-discharge relationship with measured stages and discharges, a comparison can be made that implies the channel bed has shifted. This analysis was done by USGS and is shown in Figure 4 below. The shift is the amount that needs to be added or subtracted from the stage in order for the discharge indicated by the rating table being used to most closely agree with the measured discharge. The rating used for this analysis (Rating 9) is currently in use at the station.

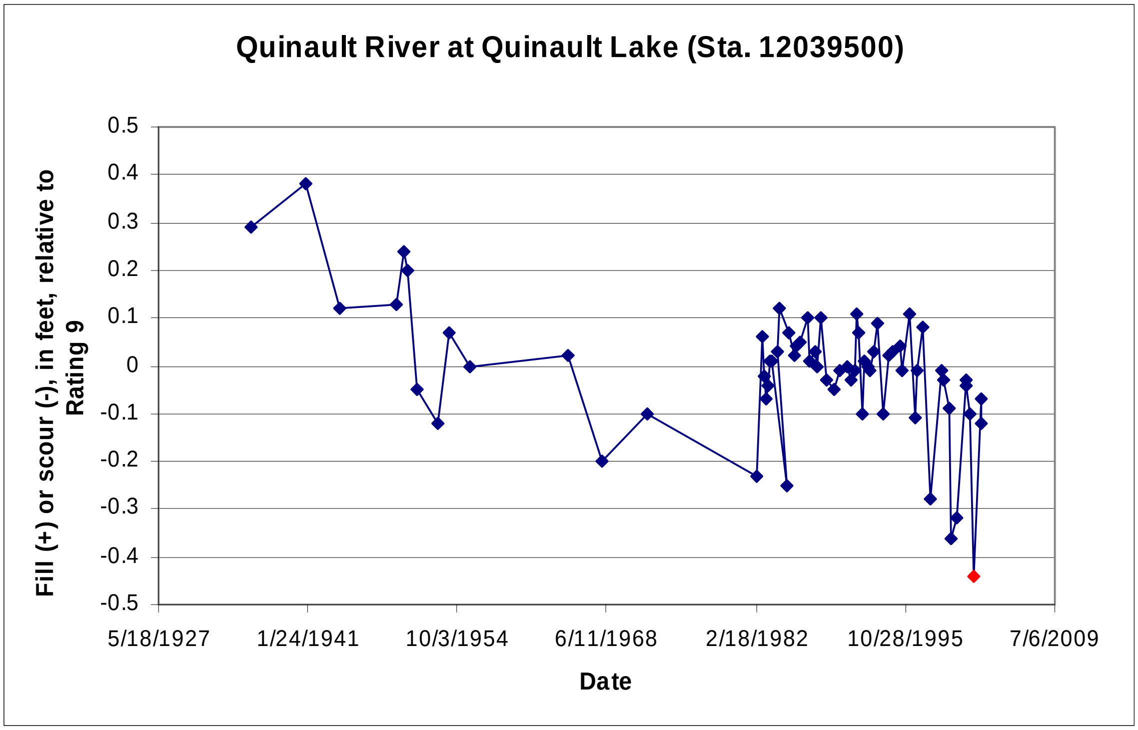


Figure 4. Shift analysis at USGS gage at outlet of Lake Quinault that indicates a possible lowering of channel bed at gaging station.

The analysis indicates there has been a gradual bed lowering at the USGS gaging station between 1935 and 2002 of about 0.5 foot (written communication from USGS). This indicates the lake elevations for a given discharge may be slightly lower today than historically. The current bed appears to fluctuate within 0.5 foot and this may be due to high flows scouring out the bed and re-deposition during subsequent lower flow periods. This can be observed from the January 2002 flood of 35,000 ft^3/s (shown as red dot in figure 1) which scoured the bed almost 0.5 foot, but the bed subsequently re-deposited in the next couple of years after the flood. However, because the change in bed elevation is small (< 0.5 foot), the 1929 and 2002 lake elevations should be close for a similar discharge. Additional evaluation of the data show that the bed can also fluctuate do to reworking during high flows.

The river discharge during the 1929 survey at the same gage location is not known because the month and day of survey are not given in the 1929 maps. However, assuming the 1929 survey was done during low flow conditions, as was the October 2002 survey the 1929 lake elevation should be similar to the 2002 level. This is a good assumption based on the split flow channels, mid-channel bars and other features delineated in the 1929 planview map. The 1929 elevations were all lowered by the difference between the 1929 and 2002 lake elevations (-2.5 m) to make a best attempt at matching the vertical datums as close as possible. Therefore, the comparison of elevations between 2002 and 1929 should be reasonable, but interpreted only on a qualitative basis since the exact 1929 to 2002 datum conversion is not known.

Comparison of 1929 to 2002 channels and river surface elevations

The 1929 channel between the lake inlet and the confluence of the North and East Fork Quinault branches was 16.8 km in length. The 2002 channel was 17.9 km in length, a little more than 1 km longer than the 1929 path. One explanation for the difference in river channel lengths could be from progradation (longitudinal growth) of the delta at the inlet to the lake. However, as a result of channel avulsions, although the delta has grown in length since 1929, the particular 2002 channel location is laterally very similar to the position of the 1929 inlet due to a recent channel avulsion. Other possible explanation for the difference in channel length is error in the 1929 survey, or that there actually was a straighter channel in 1929 that resulted in a shorter length.

Because the possible error of the 1929 survey can not be quantified, it was assumed the relative change in elevation was correct and by adjusting the vertical datum to match at the lakes, the data sets were comparable. A longitudinal profile was generated by pulling 2002 and 1929 points from GIS along the valley axis at locations of 1929 contour crossings (Figure 5). Measured water surface elevations from 2002 were used, in hope of being most comparable to elevations from1929 assumed to be representative of the low flow channel surface at a comparably low discharge.

The profile comparison indicates that, qualitatively, there has been some channel incision (bed lowering) between 1929 and 2002 between river kilometer 14 and 17 of the study reach, and that the remainder of the study reach has, on average, remained relatively stable. There do appear to be a few areas where 2002 is slightly higher than the 1929 water surface between river kilometer 3 and 10. This may be indicative of sediment waves being transported in the system more evident in 2002 due to the more detailed, continuous survey data collected as opposed to the 5-foot intervals on the 1929 river water surface. There does not appear to be any evidence of large-scale aggradation between 1929 and 2002 from this profile comparison.

References

Federal Geographic Data Committee. 1998. Geospatial Positioning Accuracy Standards Part 3: National standard for Spatial Data Accuracy, National Spatial Data Infrastructure, Subcommittee for Base Cartographic Data, Federal Geographic Data Committee, FGDC-STD-007.3-1998.

Jones, E.E. 1929. Plan and profile of Quinault River from mouth to Rustler River and Quinault Lake Dam Site, Washington, Printed in 1930, U.S. Geological Survey, Department of Interior.

Kresch, D.L. 2004. Written communication regarding shift analysis at USGS gages on Quinault River, transmitted via email.

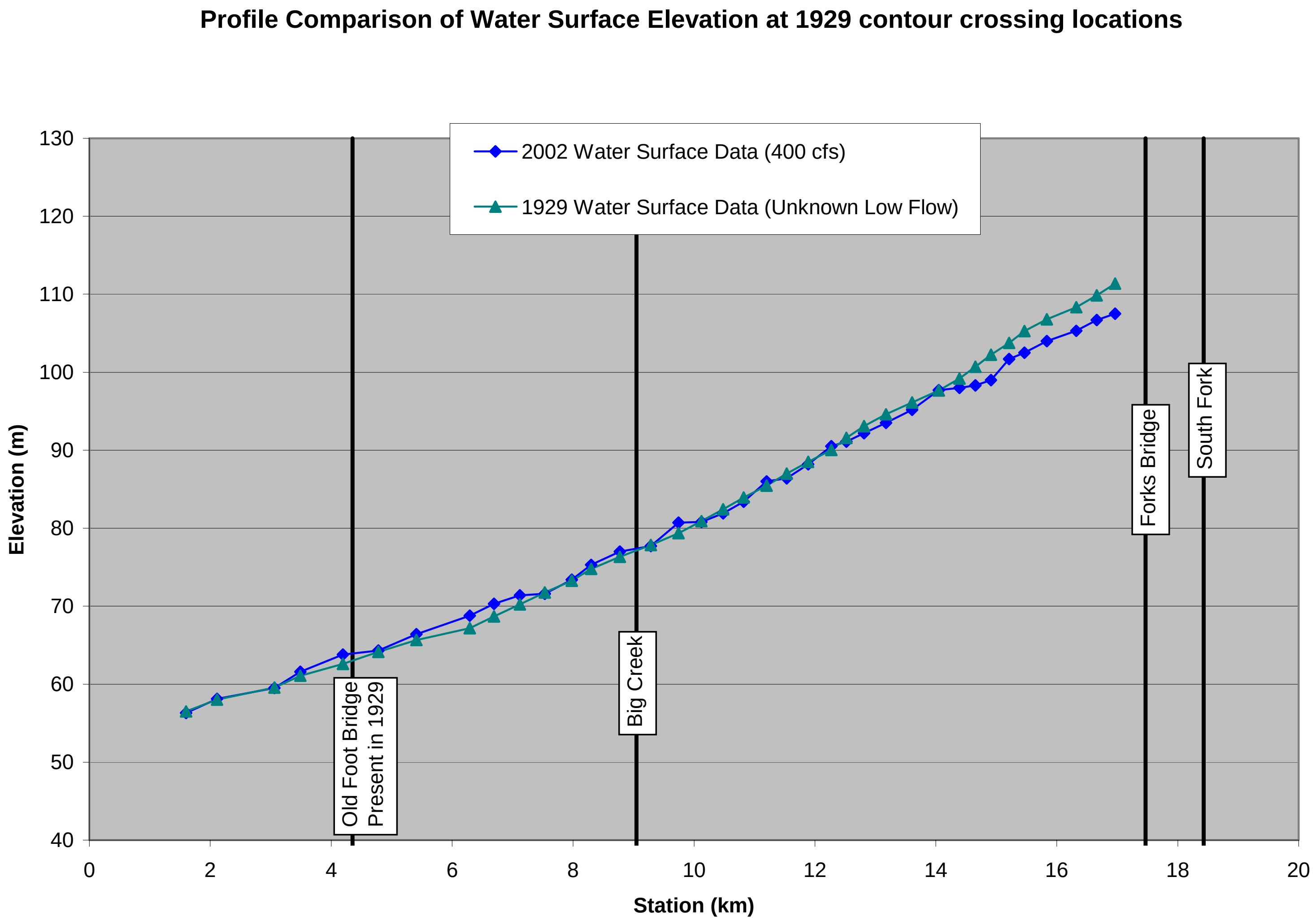


Figure 5. Qualitative comparison of 1929 to 2002 water surface profile data.

Attachment 1: Quinault 2002 Survey Control Report

The GPS control points and photography points for the Quinault survey were set and surveyed under less than ideal conditions. The area of the survey is a rain forest with heavy canopy in most places. Care and diligence were taken in point placement to assure the survey would meet the requirements of the project. Considerations for future access to the points were also deliberately considered. All necessary permissions were gained when private property was used for point placement.

The primary control points used to define the horizontal components of the survey were TEN OCLOCK (PID SY1510) and HATCHERY (PID SY5644). Both points are part of the Federal Base Control Network. TEN OCLOCK is 4.5 miles west of Amanda Park. HATCHERY is 17 miles south of Amanda Park. Note: HATCHERY is less than ideal due to vegetation restricting sky visibility.

A secondary, onsite control point 3 was also established. Point 3 has excellent sky visibility and is in a relatively secure area. Point 3 was tied to the primary control points with many hours of observation over the course of several days.

Average horizontal errors for the control points were 10 mm in the north and south components calculated at 2-sigma. Average horizontal errors for the photography points were 15 mm in the north and south components calculated at 2-sigma.

Average vertical errors for the control points were 10-12 mm in the ellipsoid heights calculated at 2-sigma. Average vertical errors for the photography points were 15-18 mm in ellipsoid heights calculated at 2-sigma.

Elevations (orthometric heights) were calculated by holding the elevation of one point, TEN OCLOCK, fixed and utilizing GEOID 99 in the adjustment. An eccentric point 9 was set and observed with an elevation transferred from H 476 (PID SY1497) to use as an elevation check. This check was satisfactory and accepted. A rigorous determination of orthometric heights was determined not to be necessary for the project. In the future, relative elevations within the project area can be obtained by using the same technique.

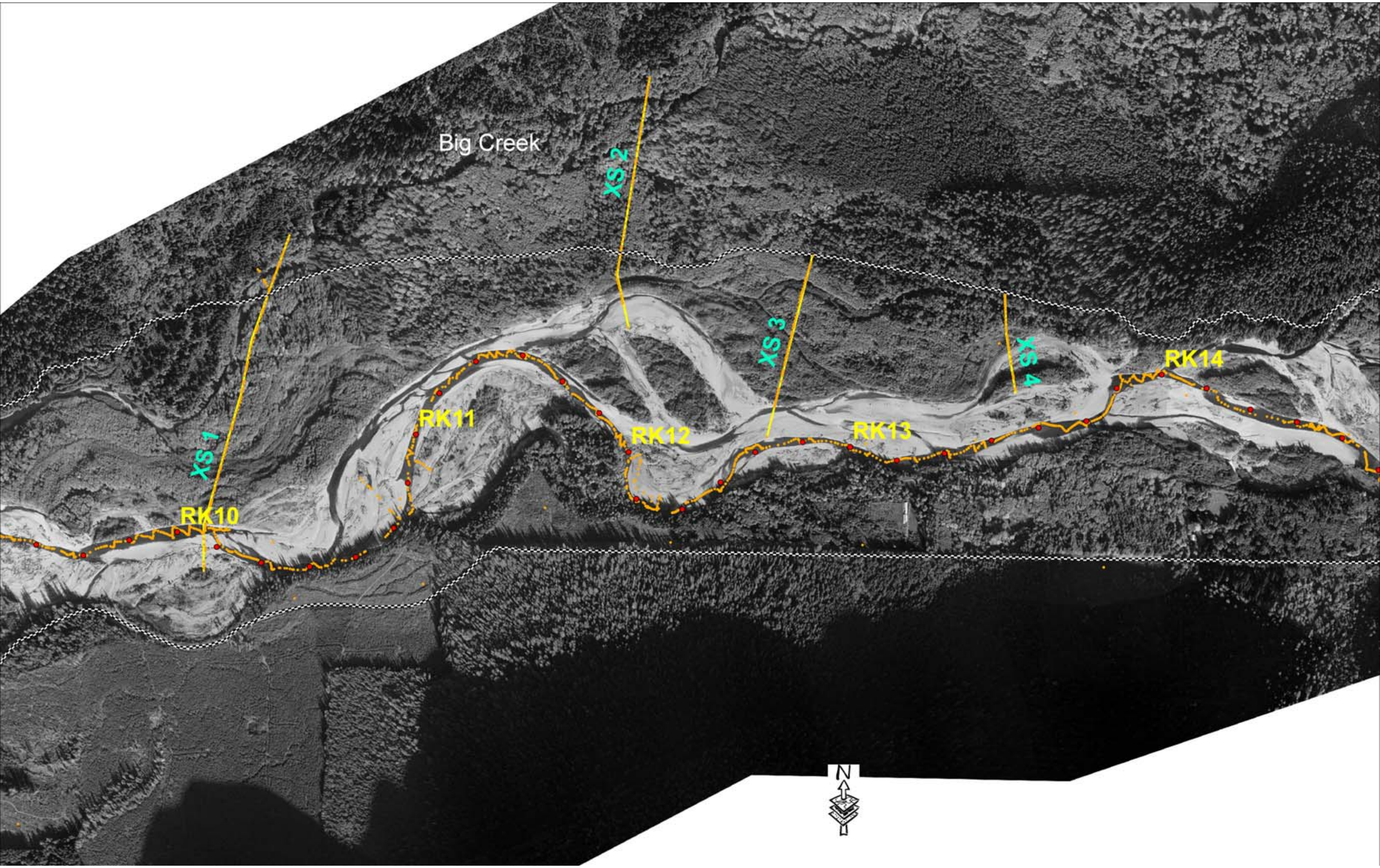
Checks performed during the hydrographic fieldwork provided checks to the GPS network and were found to be satisfactory.

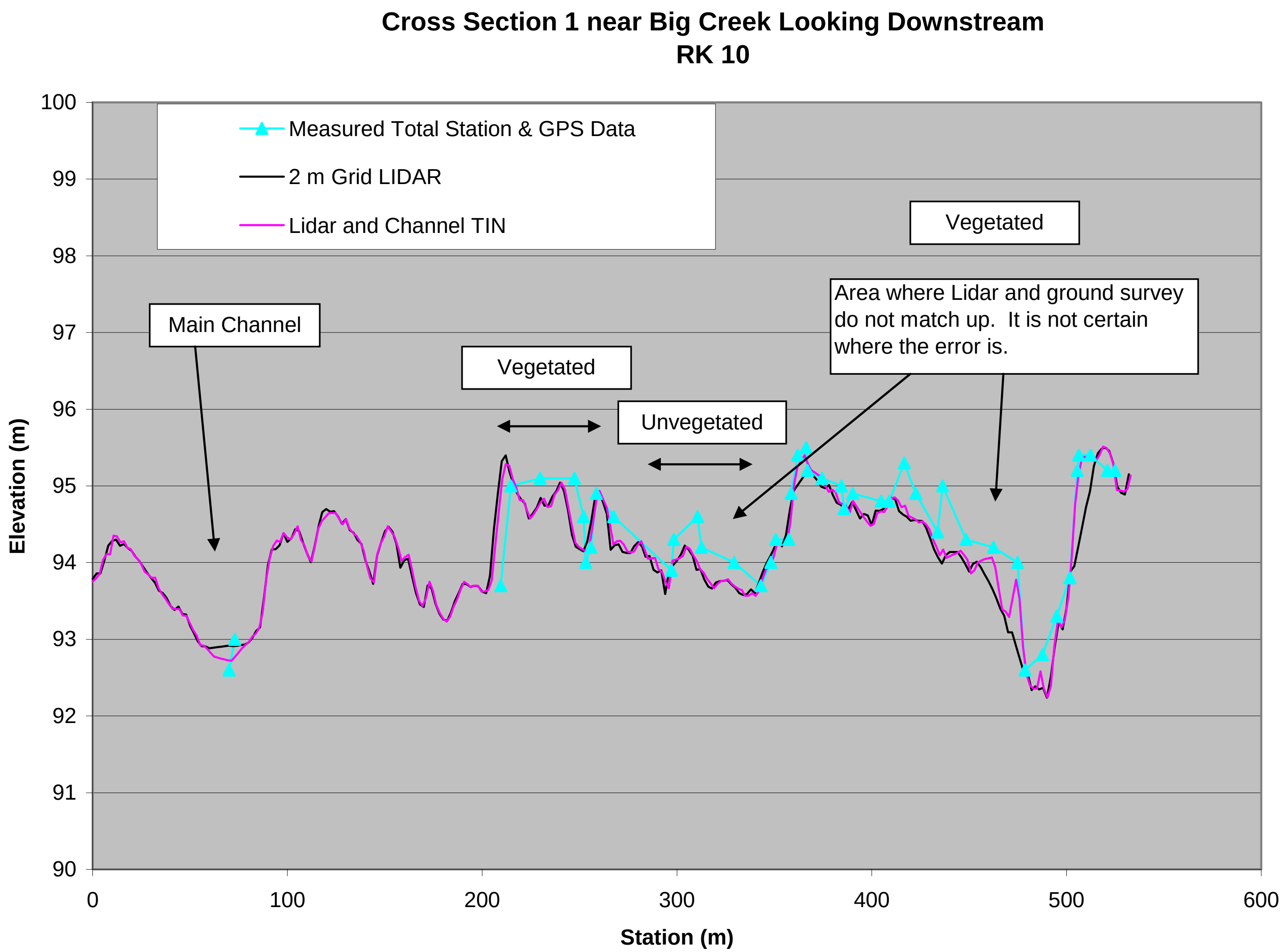
Photo Panel Point	Northing_UTM83m	Easting_UTM83m	Elevation_88m
2	5264267.446	441629.272	87.34
3	5259225.02	437604.275	59.571
5	5260623.411	439889.424	67.643
6	5262174.661	441573.417	75.169
1	5258856.384	425727.793	156.321
7	5231364.338	425406.47	36.477
102	5264801.381	447852.181	107.233
100	5264203.799	442803.656	81.832
101	5264110.853	442943.485	83.879
QUIN-8	5260622.932	436391.864	57.264
QUIN-10	5268483.316	449207.311	161.287
QUIN-7	5264105.989	445767.059	97.629
QUIN-9	5264845.238	445421.199	95.076
GPS8	5261523.884	438162.884	67.024
104	5264897.714	448548.678	112.085
105	5264683.585	448950.849	116.424
4	5260461.727	439361.876	63.693
9	5255407.016	433884.484	124.851
103	5264951.487	448744.834	113.234
106	5264714.97	448947.814	116.347
11	5262873.233	440889.612	75.113
QUIN-11	5262247.523	438395.254	77.635
QUIN-13	5266004.044	445588.733	102.958
QUIN-15	5261236.461	437797.598	63.114
QUIN-14	5267067.405	449537.839	130.356
QUIN-16	5266069.029	451335.038	125.483
QUIN-12	5266160.906	451905.943	128.275

Attachment 2: Comparison of LiDAR data to ground survey data at four cross sections

Figure Shown on Next Page:

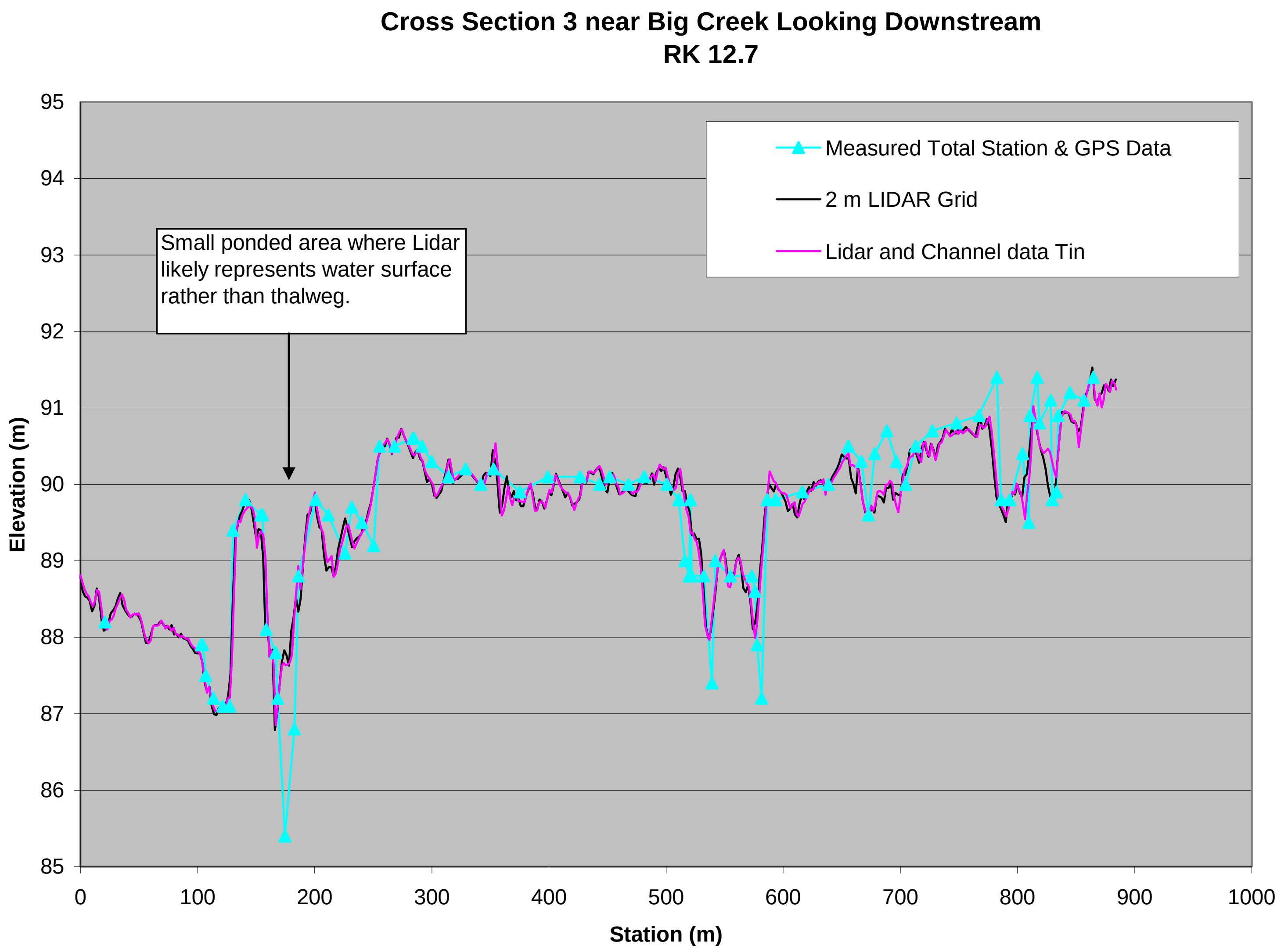
Figure 6. Location of four cross sections where LiDAR data (not shown) was compared to ground survey data (collected where orange dots and yellow lines are shown). River is flowing from left to right in photograph. River kilometers as assigned to the 2002 low flow channel are shown in yellow text and red dots.


Big Creek
XS 2
XS 1
XS 3
XS 4
RK14
RK11
RK12
RK13
RK10
N

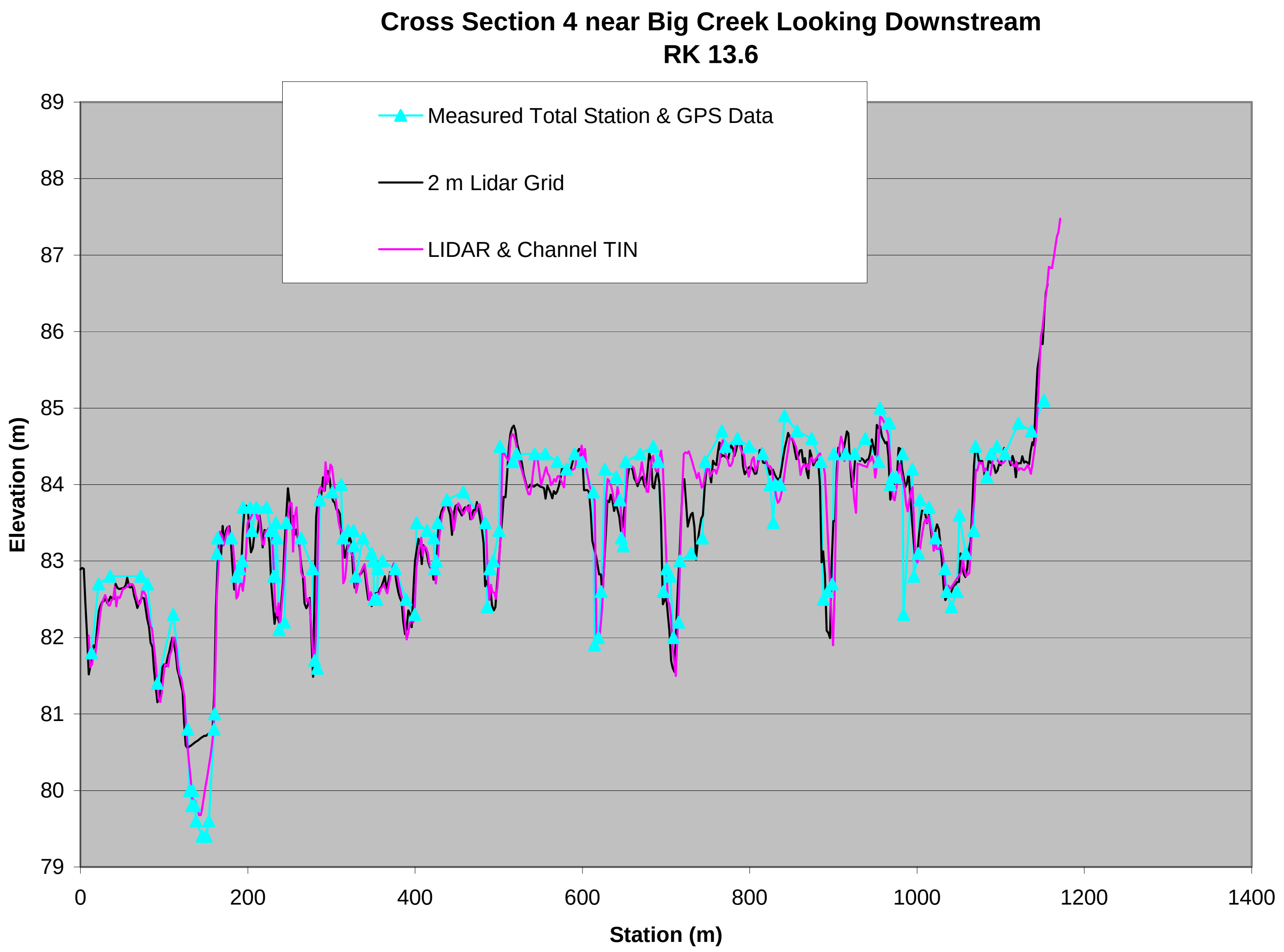


Cross Section 1 near Big Creek Looking Downstream
RK 10
Measured Total Station & GPS Data
2 m Grid LIDAR
Lidar and Channel TIN
Main Channel
Vegetated
Unvegetated
Vegetated
Area where Lidar and ground survey do not match up. It is not certain where the error is.
Elevation (m)
Station (m)
100
99
98
97
96
95
94
93
92
91
90
0
100
200
300
400
500
600

Cross Section 2 near Big Creek Looking Downstream
RK 12
Measured Total Station & GPS Data
2 m LIDAR Grid
Lidar and Channel Data TIN
Elevation (m)
95
94
93
92
91
90
89
88
87
86
85
0
100
200
300
400
500
600
Station (m)

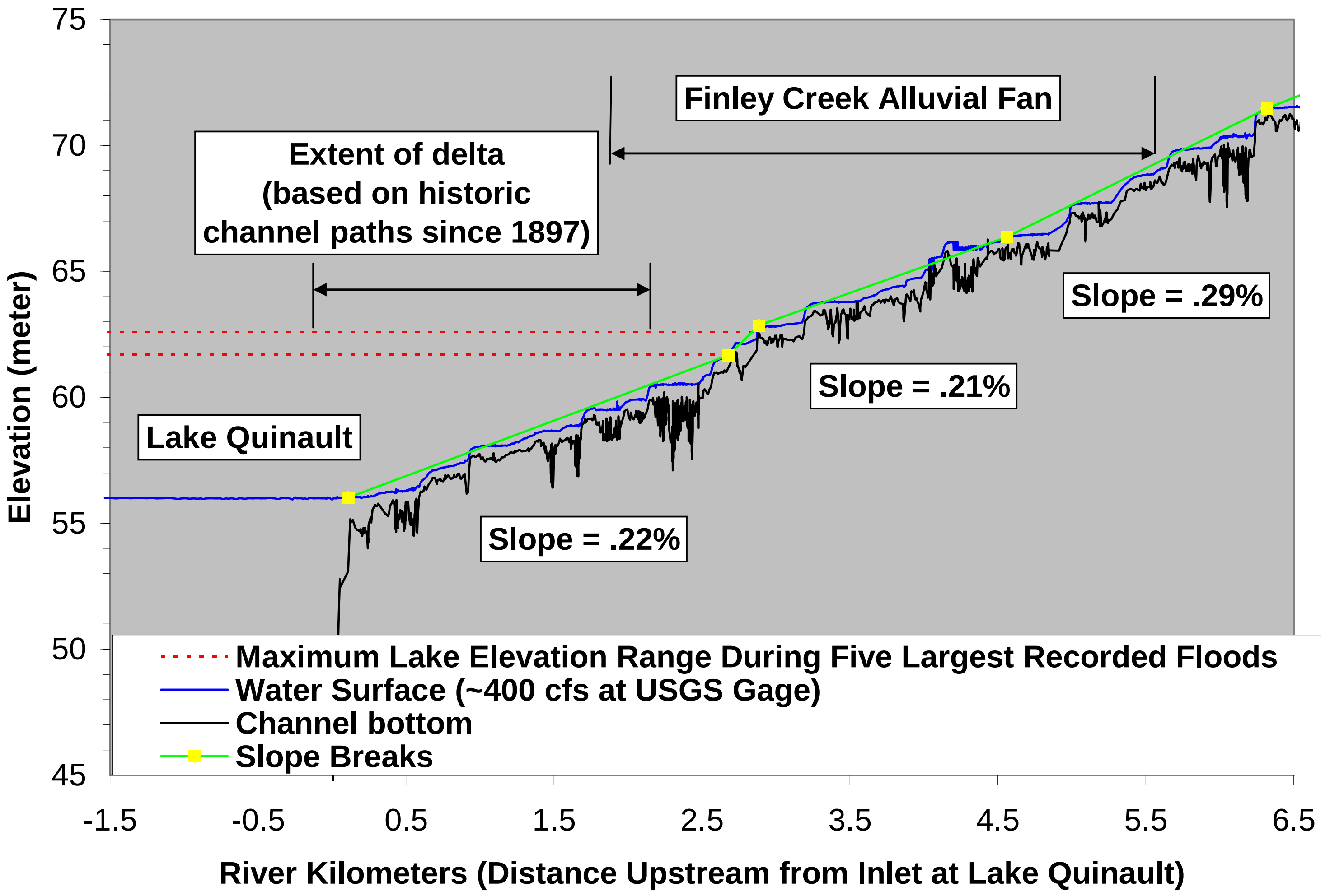


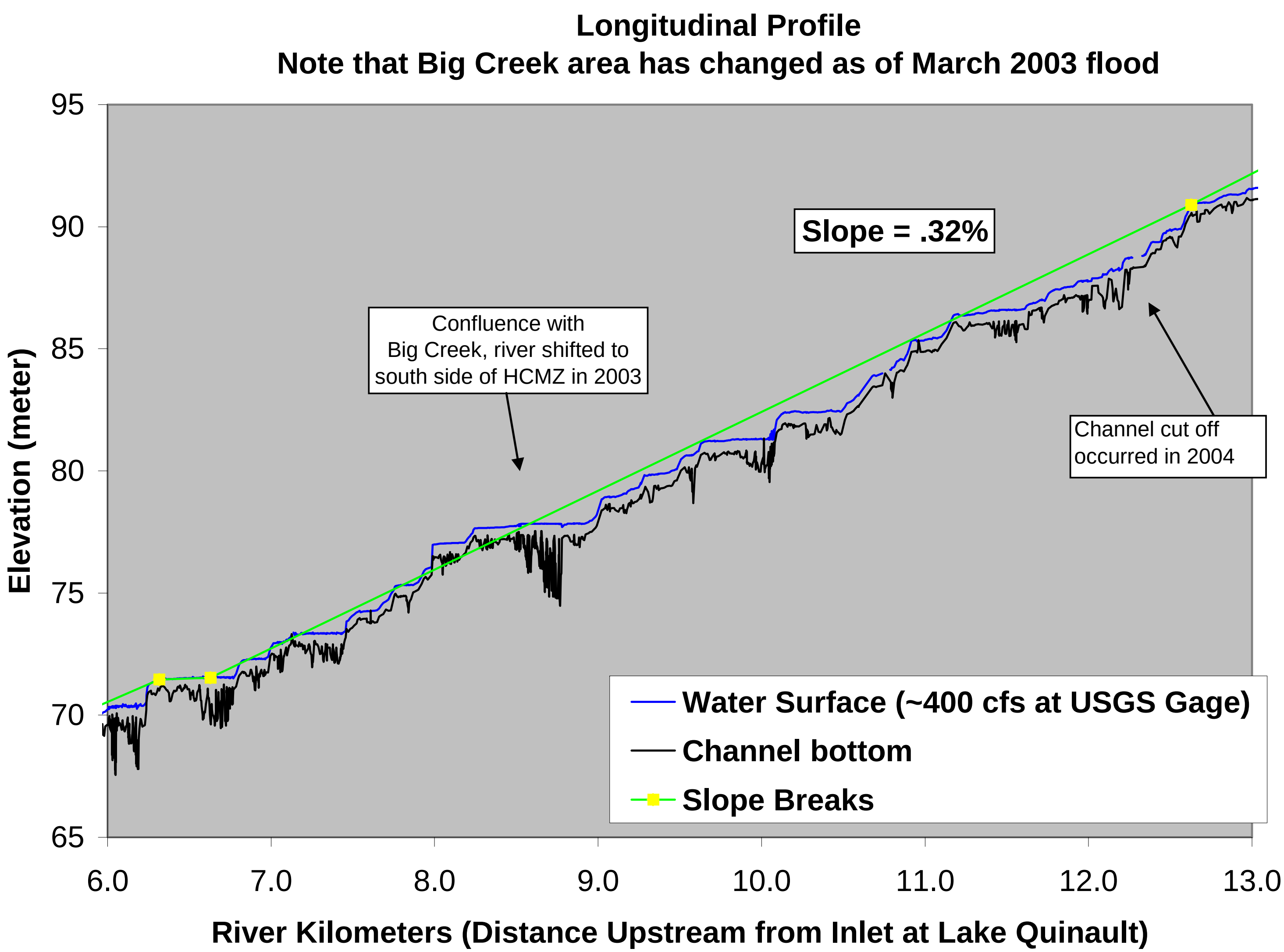
Cross Section 3 near Big Creek Looking Downstream
RK 12.7
Measured Total Station & GPS Data
2 m LIDAR Grid
Lidar and Channel data Tin
Small ponded area where Lidar likely represents water surface rather than thalweg.
Elevation (m)
95
94
93
92
91
90
89
88
87
86
85
0
100
200
300
400
500
600
700
800
900
1000
Station (m)

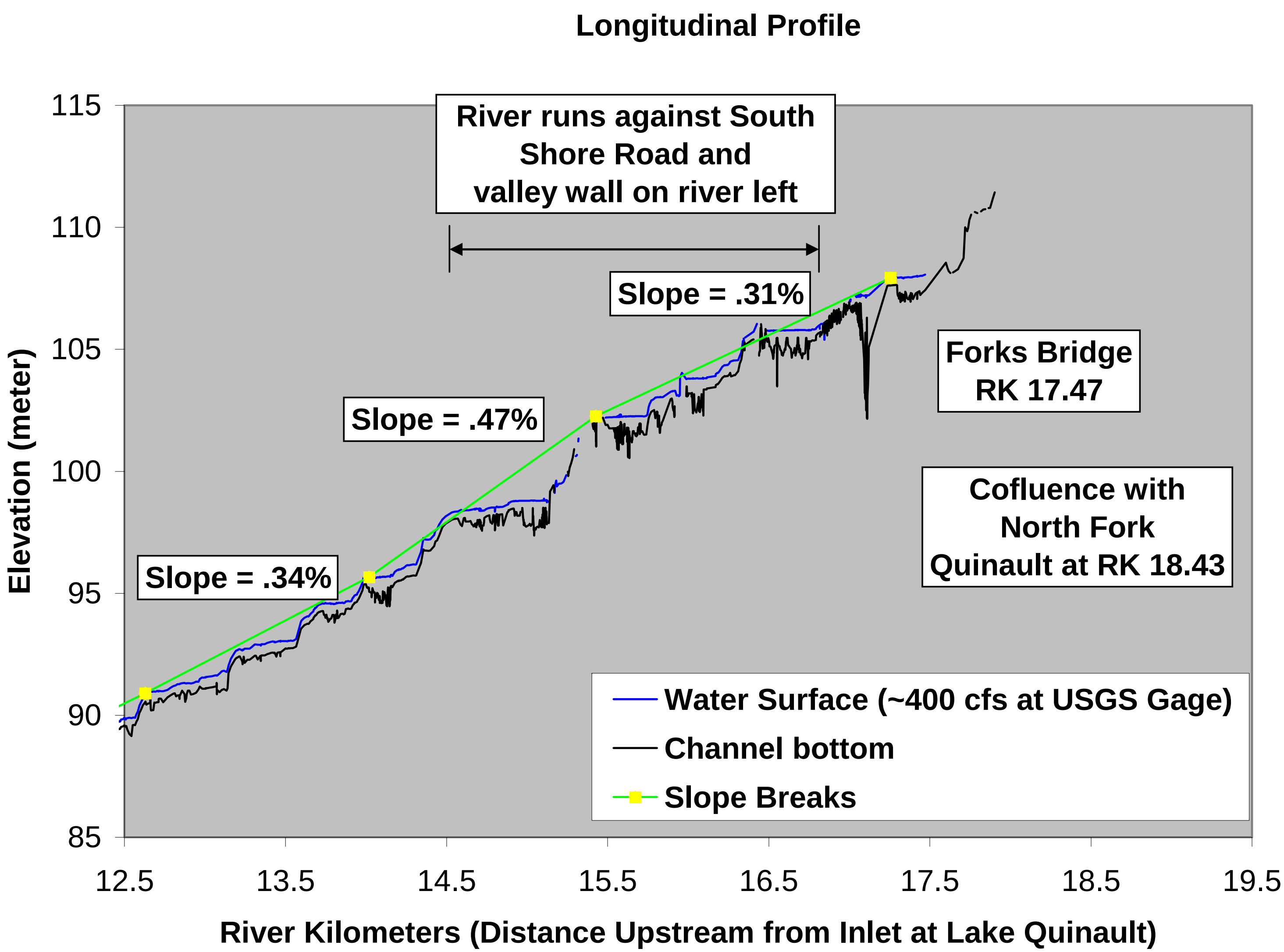

Cross Section 4 near Big Creek Looking Downstream
RK 13.6
Measured Total Station & GPS Data
2 m Lidar Grid
LIDAR & Channel TIN
Elevation (m)
Station (m)
89
88
87
86
85
84
83
82
81
80
79
0
200
400
600
800
1000
1200
1400

Attachment 3: Longitudinal profile summaries of low flow Quinault River channel.

Longitudinal Profile




Longitudinal Profile
Note that Big Creek area has changed as of March 2003 flood
Elevation (meter)
95
90
85
80
75
70
65
Slope = .32%
Confluence with Big Creek, river shifted to south side of HCMZ in 2003
Channel cut off occurred in 2004
Water Surface (~400 cfs at USGS Gage)
Channel bottom
Slope Breaks
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
River Kilometers (Distance Upstream from Inlet at Lake Quinault)



Longitudinal Profile
River runs against South Shore Road and valley wall on river left
Slope = .31%
Slope = .47%
Slope = .34%
Forks Bridge RK 17.47
Cofluence with North Fork Quinault at RK 18.43
Water Surface (~400 cfs at USGS Gage)
Channel bottom
Slope Breaks
Elevation (meter)
115
110
105
100
95
90
85
12.5
13.5
14.5
15.5
16.5
17.5
18.5
19.5
River Kilometers (Distance Upstream from Inlet at Lake Quinault)